# Simulation of Surface Erosion on a Logging Road in the Jackson Demonstration State Forest[1]

## Teresa Ish[2] and David Tomberlin[3]

## Abstract

In constructing management models for the control of sediment delivery to streams, we have used a simulation model of road surface erosion known as the Watershed Erosion Prediction Project (WEPP) model, developed by the USDA Forest Service. This model predicts discharge, erosion, and sediment delivery at the road segment level, based on a stochastic climate simulator and road segment characteristics. To apply the WEPP model, we collected data on road segment dimensions, design and slope for 57 contiguous road segments totaling 3.5 miles of Road 630 on the Jackson Demonstration State Forest.

Results of the simulation exercise suggest a long-term average annual erosion rate on Road 630 of 20.8 metric tons per kilometer per year, with a standard deviation of seven metric tons per kilometer per year. Overall, we found the WEPP software well designed and flexible enough to meet our needs, as it allows specification of many different road and environmental parameters. One shortcoming for our purposes was that WEPP's stochastic climate generator does not simulate serial correlation. We have begun a field study of road surface erosion rates that will enable evaluation of the predictive ability of the WEPP model in the redwood region.

*Key words: erosion simulation, road surface erosion, and WEPP*

## Introduction

Because erosion can impair road function and contribute to excess sedimentation in fish-bearing streams, road erosion control is a high priority for many landowners. While the relative effectiveness of different erosion control treatments on roads is not yet well known, a few studies have been completed (Burroughs and King 1989, Madej 2001), and others are underway. More fundamentally, data on road erosion are relatively scarce in comparison with the data available on sediment loads in streams. Having information only on in-stream sediment makes the attribution of erosion to a particular type, amount or locality of soil loss at the source difficult. Without these basic data, the risks and benefits of different road erosion treatments cannot be characterized empirically.

Road erosion may take the form of mass wasting (for example, fill failures), fluvial erosion (for example, ditch scour) or surface erosion. Mass wasting is generally thought to be the most important of these in the redwood region, while

---

[1] This paper was presented at the Redwood Science Symposium: What does the future hold? March 15-17, 2004, Rohnert Park, California.

[2] Staff Research Associate, University of California, Santa Cruz, under contract to the National Marine Fisheries Service. Current affiliation: Sustainable Fishery Advocates, P.O. Box 233, Santa Cruz CA 95061. email: ishsurf@yahoo.com

[3] National Marine Fisheries Service, Santa Cruz, CA. email: david.tomberlin@noaa.gov

surface erosion is generally considered the least important. Perhaps because of this belief, during the course of our work on decision models for erosion control we were unable to find any published time series of road surface erosion rates. To develop estimates of road surface erosion, we turned to a simulation model known as the Watershed Erosion Prediction Project (WEPP) model. This paper describes our application of the WEPP model to Road 630 on the Jackson Demonstration State Forest in Mendocino County, summarizes the results obtained, and concludes with an assessment of the model's usefulness for our purpose, which was to develop input data for a dynamic optimization model of erosion management.

## *Study Site*

Road 630 is a partially rocked road located in the Middle Fork Caspar Creek watershed. This watershed covers approximately 1300 acres, with elevation ranging from 100 to 1000 feet and slopes from zero to 100 percent. The climate is Mediterranean, with average annual precipitation between 40 and 70 inches. Second- and third-growth redwood and Douglas-fir are the dominant vegetative community, and streams within the watershed support both coho salmon and steelhead trout. The coastal belt of the Franciscan assemblage, consisting of marine sedimentary and volcanic rocks, underlies the watershed. For most of its length, Road 630 runs mid-slope along the Middle Fork of Caspar Creek, where predominant soil types are the Dehaven-Hotel complex and Irmulco-Tramway complex at lower elevations and Vandamme at higher elevations. For most of its length, the road is crowned with an inside ditch. A recent inventory of erosion potential on the road suggests that both mass wasting (landslides or stream crossing failures) and chronic surface erosion are likely to deliver significant volumes of sediment to nearby Caspar Creek (Pacific Watershed Associates 2001).

# Methods

## *The WEPP Model*

The Water Erosion Prediction Project model was developed by the USDA Agricultural Research Service to estimate soil loss on rangeland and cropland (Flanagan and Nearing 1995). It has been adapted by the USDA Forest Service for use on forestlands and forest roads (Elliott and others 1999). The model includes 12 conceptual components that influence soil detachment, among which are climate, irrigation, hydrology, water balance residue, management and composition, tillage impacts on infiltration, and deposition. A full description of the model is available in Flanagan and Livingston (1995).

The unit of analysis for the WEPP Road application is the road segment, defined in hydrologic terms: a segment is the area of road from which surface flow exits at a common point, such as a ditch relief culvert or water bar. Application of the model requires input of road segment characteristics (described in the next section) and specification of model parameters related to climate, soil characteristics and management practices. WEPP provides a wide variety of pre-specified parameter files (for example, climate in Fort Bragg, or Dehaven soil characteristics) and also allows the user to adapt these parameters or create an entirely new parameter profile. WEPP includes a stochastic climate generator known as Cligen, which generates rainfall and storm frequency intended to reflect historical data for a specific study site.

WEPP is available in both DOS and Windows forms. We used the Windows

version, which allows the model to be specified within an easy-to-use graphical user interface.

## Data Collection

Data for Road 630 were collected on June 24 and June 25, 2003. A total of 57 contiguous segments were identified, totaling 3.5 miles of road. Data collected for each segment included road grade, segment length, segment width, ditch presence, vegetative level in ditch, and critical features such as rutting or standing water. Because of the difficulty of ascertaining how much of the road width would contribute to point-source runoff from the segment, three values were recorded for width: a low value corresponding to the traveled way, a medium value indicating measurement from the outer berm or beginning of loose detritus on the fill-slope side of the road to the center of the ditch (if present) and a high value indicating measurement to the start of forest vegetation on both sides. Where length data for a segment could not be taken with a single measurement, the segment was broken into sub-segments.

## Specification of Simulation Parameters

For each road segment, we specified soil type and road configuration (in other words, insloped or not, ditch present or not) for the simulation. Because road construction may have altered the physical properties of the soil types found in this region, we standardized the soil type to 'sandy loam road surface' for all segments during our basic simulations, and reserved the use of segment-specific soil types (Dehaven, Tramway, and Vandamme soil, which are available in the standard WEPP distribution) for the sensitivity analysis. WEPP allowed for the inclusion of sub-segment slope and length data. We selected the Fort Bragg, CA, climate data for our simulation from the climate models provided by WEPP. We used a continuous simulation over a 1000-year time horizon.

Due to the difficulty of matching the road segments to the stylized geometry of the WEPP model, we initially explored two road configurations for Road 630. The first scenario, labeled 'insloped' below, designated each sub-segment either insloped road with vegetated or rocked ditch, or outsloped road with rutting; only six of fifty-seven segments were designated outsloped. The second configuration, labeled 'outsloped' below, designated all segments as outsloped, some rutted and some not. Given that most segments were crowned or of ambiguous configuration due to the road being unmaintained, we averaged the results of simulations for these two configurations to arrive at a summary estimate, labeled 'best estimate' below.

## Output Analysis

Model projections for soil loss were reported by WEPP in $kg/m^2/yr$. Due to uncertainty about how much of the road width would contribute to point-source runoff from each segment, we ran the model for each segment with low, medium, and high width estimates. With these estimates, we calculated metric tons of soil lost per kilometer (mt/km) of road per year using the reported WEPP soil loss in $kg/m^2$ and a representative soil bulk density estimate of $1100 \ kg/m^3$ (Wosika 1981, pp. 47-48).

# Results

We generated two basic estimates of long-run rates of surface erosion on Road 630, both based on 1000-year simulations and both calculated as the long-run weighted average[4] soil loss for the entire road. The first simulation, 'insloped,' in which most segments were classified as insloped (n = 51) while those with ruts (n = 6) were classified as outsloped, generated an estimate for the rate of annual surface erosion of.18.8 mt/km/yr ± 7.2 (127 yd³/yr ± 45). The second simulation, 'outsloped,' in which for comparative purposes all segments (n = 57) were classified as outsloped, generated an estimate of 22.0 mt/km/yr ± 6.8 (148 y³/yr ± 47). This second simulation yielded a higher estimate because outsloped segments were assumed to require more frequent grading. Further averaging over these two putative road configurations to arrive at our 'best estimate' yielded estimated soil loss of 20.4 mt/km/yr ± 7.0. Some external corroboration is provided by a comparison to erosion estimates from a field survey, which estimated future annual soil loss on Road 630 at 66 to 330 yd³/yr (10 to 49 mt/km/yr), depending on use (Pacific Watershed Associates 2001). Our predicted losses are well within this range.

On individual segments, soil loss (again, after averaging over estimates by road width) ranged from zero mt/km/yr to 41.8 mt/km/yr.

## *Sensitivity Analysis*

As mentioned, the 'outsloped' simulation yielded somewhat greater soil loss than did the 'insloped' simulation *(fig. 1)*. To examine the results' sensitivity to soil type, we re-ran these two basic simulations, substituting site-specific soil types (Dehaven, Tramway, and Vandamme) for the generic 'sandy loam road surface.' Under the insloped road configuration, subsituting particular soil types resulted in somewhat lower estimated soil loss than under the sandy loam soil type, however this pattern was not apparent under the 'outsloped' road configuration. When the two configurations were averaged, using the 'sandy loam road surface' soil type tended to result in a lower estimated average soil loss than all other soil types and variants on these types, though this effect varied by segment *(table 1)*. Further tests of model sensitivity, for example, altering albedo or critical shear, had little effect on estimated soil loss.

Variation in soil loss for each segment as well as for the entire road was more heavily influenced by the measured width of the road than by changing parameters of soil or management type *(table 1)*. For the segment (number 37) with the largest difference between the low and high widths, soil loss was over 400 percent greater using the high width than the low width. This is in contrast to the difference in soil lost by varying soil or management parameters, where the largest difference was about 50 percent from the base scenario. Using the soil types specific to each segment had a larger effect than management type, but this effect was still small in comparison to the effect of measurement error in width.

---

[4] The low and high width estimates were weighted by 0.2 each and the medium width estimate was weighted 0.6.
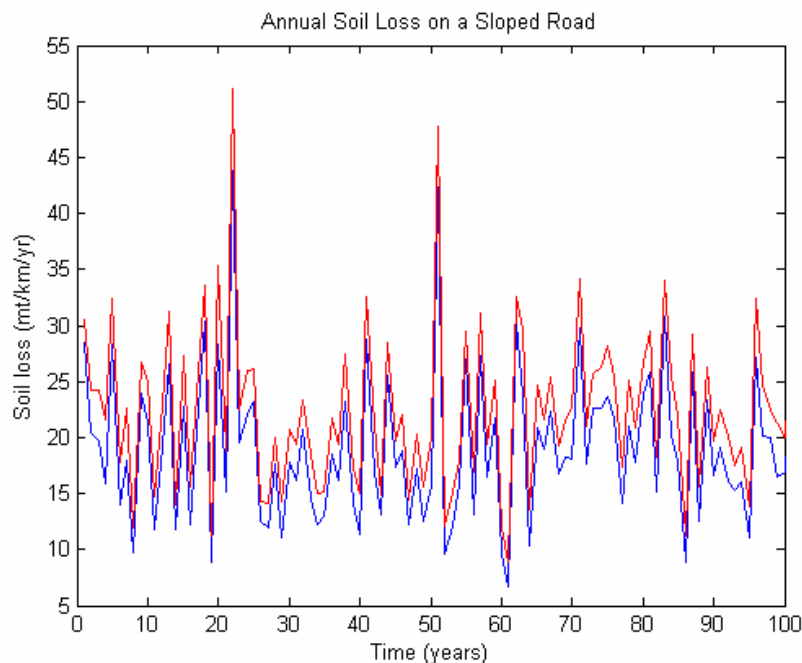
**Figure 1**—Simulated soil loss, after taking the weighted average of width, for 100 years. Red shows the outsloped road configuration, blue shows the insloped road configuration. Note this figure does not show the averaged 'best estimate' scenario.

**Table 1**—*Estimated soil loss (in mt/km/yr) on two segments and the entire road at the low, medium, and high width measurements, and with different road configurations and soil types. Segments 2 and 37 represent extreme examples of measurement differences between the low and high widths.*

| | Low width | Medium width | High width | Weighted mean | Percent difference from base scenario |
|---|---|---|---|---|---|
| **Best estimate scenario, uniform sandy loam soil** | | | | | |
| Segment 2 | 7.8 | 7.8 | 7.8 | 7.8 | --- |
| Segment 37 | 13.3 | 19.5 | 67.1 | 27.8 | --- |
| Entire road | 13.3 | 20.0 | 28.8 | 20.4 | --- |
| **Insloped scenario, uniform sandy loam soil** | | | | | |
| Segment 2 | 6.5 | 6.5 | 6.5 | 6.5 | −17 |
| Segment 37 | 13.2 | 19.3 | 66.6 | 27.5 | −1 |
| Entire road | 12.2 | 18.5 | 26.6 | 18.8 | −8 |
| **Outsloped scenario, uniform sandy loam soil** | | | | | |
| Segment 2 | 9.0 | 9.0 | 9.0 | 9.0 | 15 |
| Segment 37 | 13.4 | 19.6 | 67.7 | 28.0 | 1 |
| Entire road | 14.3 | 21.6 | 31.0 | 22.0 | 8 |
| **Best estimate scenario, segment-specific soil type** | | | | | |
| Segment 2 | 9.8 | 9.8 | 9.8 | 9.8 | 25 |
| Segment 37 | 10.8 | 15.8 | 54.6 | 22.6 | −19 |
| Entire road | 20.6 | 30.6 | 43.0 | 31.1 | 52 |

# Discussion

Our primary goal in using the WEPP model was to generate estimates of the long-run mean and variance of surface erosion rates on Road 630. The model allowed us to accomplish this goal fairly easily, and with a reasonable degree of confidence in the results. The WEPP model incorporates the most important hydrological and geophysical information needed to make basic predictions of surface erosion rates on logging roads. Further, the graphical user interface and the many data files packaged with the WEPP software (on climate, soil, management, and so forth) make it easy to apply the model to a particular road. The user can easily reflect local conditions by altering parameter values. In testing the sensitivity of model projections to a range of different characterizations of soil and road geometry that might reasonably apply to our study site, we found that model projections for the whole road were generally within a 20 percent range of each other. Since our purpose was to generate order-of-magnitude estimates rather than precise forecasts, we were pleased with this stability. In our case, uncertainty regarding the size of each segment's catchment on soil loss/km/yr dominated the effect of parameter specification (in other words, soil characteristics, such as critical shear or albedo, and road configuration).

An important secondary goal for us was to generate a model of the dynamics of road surface erosion, and for this purpose we found the model was less useful, specifically because of the way the Cligen stochastic climate generator is designed. Cligen produces rainfall data so that the final distribution reflects the historical distribution of rainfall data for the region in question, but it does not have the ability to generate precipitation data that incorporate serial correlation. We tested for serial correlation in the precipitation time series for Fort Bragg from 1913 to 2002 and found more support for the hypotheses that precipitation is generated by an autoregressive or moving average process than by a white noise process. Because Cligen does not provide a means to capture serial correlation, the erosion data generated by WEPP cannot reflect the serial correlation we found in the precipitation history. To the extent that precipitation influences interannual variability in road surface erosion, the formulation of the WEPP model prevents simulated erosion data from reflecting the medium-term dynamics of the surface erosion. Land managers or researchers interested in WEPP-based Monte Carlo simulation should also be aware that the WEPP's current configuration requires resetting the Cligen climate model with each simulation, because the erosion model itself is deterministic.

Our interest in generating a time series of road surface erosion rates arose from the need for this data as input to a dynamic optimization model of erosion control. For this purpose, we needed the long-run mean and variance estimates provided by WEPP, and supplemented WEPP results with a proxy for inter-annual erosion dynamics derived from analysis of historical precipitation data in the study area. While not ideal, this approach seems like a reasonable blend of simulation and time series analysis.

The biggest question, of course, is whether the WEPP model projections for Road 630 are in some sense reliable, and whether the model could usefully be applied to other roads in the redwood region. At this time, we have no basis for judging this. We have begun a project with the California Department of Forestry to collect field data on erosion rates over time. Once this project has produced several years of data, it will be possible to begin empirical testing of the WEPP model's ability to forecast erosion rates in the redwood region.

## Acknowledgments

We thank Bill Elliott (USDA Forest Service) for generously sharing his experience and expertise with the WEPP model. For help with the field component of this study, we thank Brian Barrett, Bill Baxter, and Brian Bishop from the California Department of Forestry and Fire Protection and Melissa Chaney and Wes Silverthorne of the National Marine Fisheries Service.

## References

Burroughs, E.R., Jr.; King, J.G. 1989. **Reduction of soil erosion on forest roads.** Gen. Tech. Rep. INT-264. Ogden, UT: Intermountain Research Station, Forest Service, U.S. Department of Agriculture; 21 p.

Elliot, W.J.; Hall, D.E.; Graves, S.R. 1999. **Predicting sedimentation from forest roads**. Journal of Forestry 97(8): 23-29.

Flanagan, D.C.; Livingston, S.J., eds. 1995**. USDA-water erosion prediction project: user summary**. NSERL Report No. 11. West Lafayette, IN: USDA-ARS National Soil Erosion Research Laboratory.

Madej, M.A. 2001. **Erosion and sediment delivery following removal of forest roads**. Earth Surface Processes and Landforms 26: 175-190.

Pacific Watershed Associates. 2001. **Summary report, 2001 S.B. 271 Caspar Creek demonstration road assessment and decommissioning plan for Jackson Demonstration State Forest Road 630**. Prepared for California Department of Forestry and Fire Protection and California Department of Fish and Game. Arcata, CA: Pacific Watershed Associates.

Wosika, E.P. 1981. **Hydrologic properties of one major and two minor soil series of the coast ranges of Northern California**. Arcata, CA: Humboldt State Univ.; 150 p. M.S. thesis. *Available at* http://www.fs.fed.us/psw/rsl/projects/water/WosikaMS.pdf

# Proceedings of the Redwood Region Forest Science Symposium: What Does the Future Hold?

**Technical Editors**

Richard B. Standiford, Gregory A. Giusti, Yana Valachovic,
William J. Zielinski, and Michael J. Furniss

**March 15–17, 2004**

**Rohnert Park California**